Eco-Route
Project #19

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1.0 Executive Summary

Our project was to design a navigation system that would generate an optimal route based on minimal fuel consumption. The system also needed to record real-time fuel consumption along with driving habits to evaluate the optimal route. The customer requirements were translated into three main engineering specifications: a predictive model to determine the most fuel efficient route to a destination, a piece of in-vehicle navigation hardware that will transmit the route to the driver and record driver habits as well as fuel economy, and a computer/internet database that will store trip information and modify the navigation program for improved fuel usage in the future.

Our team has developed a proof of concept model for this navigation system. This concept model is a fuel consumption model of a section of Ann Arbor. It predicts the route of least fuel consumption and how much fuel will be consumed on that route. The proof of concept also includes a trip analysis program that will analyze actual data recorded from the vehicle during a test run of the optimized route. If the optimized route found by our navigation system is indeed the most fuel efficient route after testing several routes, then the proof of concept will be verified as a viable solution.

Our main efforts were focused on quantifying the traffic model of Ann Arbor from our chosen start to destination. We chose a route to study and will quantify factors that contribute to fuel efficiency i.e. speed limits and total distance. As an initial guess, equations of motion that calculate energy used were employed to estimate fuel used on a given route. This initial estimate was then multiplied by a vehicle efficiency to predict fuel used. This estimate was then verified by taking actual test data on fuel consumed and comparing it to the initial guess of 15% efficiency. Efficiency curves were then generated that more accurately predict fuel consumption, so the prediction would be within 10% of actual fuel consumed.

First and foremost, the trips suggested by the system *must* minimize gas consumption. Second, the system must be adaptive to the point where previous trip information can be analyzed. If the proof of concept is verified, trip information will be stored in a database in order to find optimal fuel routes in the future. This will enable our system to be a learning algorithm that can compare actual data to hypothesized optimized routes. Finally, the program must be able to communicate its trip recommendations to the driver. Poor driving habits are a major contributor to low fuel economy and thus must be addressed by our system.

2.0 Introduction
Currently, there are many computer based navigation programs on the market such as Mapquest© and Google Maps. These mapping programs give the user a route based on the shortest distance from beginning to end point, or fastest time of travel. The Eco-Route project seeks to design a navigation system to find the most fuel efficient route from point A to B. By finding the most fuel efficient route, the project will be instrumental in reducing fuel consumption in the U.S. and abroad if implemented elsewhere. Professor Skerlos sponsored this design project.

3.0 Problem Description
The company that we worked with was Ford Motor Company, particularly the Piquette Project. This project was aimed at taking Ford out of the garage and into the home to make peoples lives more efficient. The efficiency of a person's vehicle is a large part of this considering the negative effects vehicles have on the environment. Our project is called Eco-Route and was aimed at maximizing the efficiency of a vehicle while minimizing negative effects on the environment.

This project was an offshoot of a Bluelab project entitled *Aware at Home*. The *Aware at Home* project sought to track water, gas, and energy consumption in the household. This was done though computer monitoring and data collection of utilities used. The eco-route program intends to extend the fuel monitoring arm of *Aware at Home* to the daily drive.

Our project was to design an energy management system for personal vehicles. The focus was to determine the optimal route with respect to minimizing fuel consumption. There are presently many computer programs that will calculate the shortest or fastest route to a given location based on algorithms. However, to our knowledge there is not yet an algorithm that calculates a route that is best for the environment. One of the aspects of our project will be to make a computer algorithm that calculates the optimal driving routes based upon minimal gas consumption while taking into account heavy traffic areas and construction zones. These areas often require vehicles to slow down or stop, in which case they are running and burning gas, yet not traveling. In order to accomplish this, the computer at home must interface with the vehicle.

Due to time constraint and limited programming knowledge of our team we have scaled our project to generate a proof of concept. Presented below is the vision of the EcoRoute and can also be seen in Appendix A on page 22.

4.0 Information Sources
Information has been found on current navigation systems and minimizing fuel consumption. Benchmarks include mapping websites and vehicle navigation systems on phone or PDA. Information was gathered from several sources including patents, the University of Michigan Library, and Google.

Currently there are four major mapping websites that can provide directions on the road including Google Local, Mapquest©, and Windows Local Live and Yahoo Local maps. Google Local and Windows Local Live offer a feature that allows one to view detailed images of U.S. landscapes. Local Live provides you with a bird's eye image of the destination, but is only

available in metropolitan areas. Yahoo local maps provide information on current traffic speeds on major roads and highways and allows the user to create routes with multiple stops. The current problem with technology advancing in this area is the inaccuracy of data. (Capen, 2006)

Some cell phones have GPS capability to receive driving directions. Current products include: GPS-enabled phones that operate Mapquest© and TeleNav; Gate5's Smart2go on Bluetooth-enabled phones; Microsoft Windows Mobile phones and PDAs, the PalmOne Treo 650, and Tungsten T3. The Smart2go works by looking for the Bluetooth signal from the GPS receiver and transfers the information to the handset. In order to use Smart2go, a memory card is needed to store supplied data such as Tele Atlas maps. Current drawbacks to some of the products include slow information loading time and the possibility that directions may be off by a few blocks due to a weak GPS signal.   A major drawback is the size of the screen in order to look at maps (Aquino, 2005). Also on the market are portable GPS devices that store maps on an external memory card or a hard-drive and offer a touch screen (Capen, 2006).

In Europe, a fuel-efficiency support tool was designed to act as an advisory system to the driver with manual transmissions. This system has three components: inputs, a data processing module and a human-machine interface. Inputs of the system include vehicle speed, engine speed, clutch position, gear position, accelerator position, steering angle and brake force. After the data has been processed, the interface will give advice to the driver regarding there driving style. An example of this is "shift earlier from 2nd to 3rd gear" (van der Voort, 2001).

Similarly, BMW is developing a system called Situation Drive Train Management (SAM) that lowers fuel consumption based on driving style and other factors. SAM mimics the driving process by making longitudinal driving decisions. The system collects information from road maps, a navigation system, distance sensors and telemetric instruments. The system is then evaluated with respect to minimal fuel consumption, safety, traffic flow and time requirement. Also the system optimizes driving strategies by recording and evaluating traffic situations. Outputs include active cruise control and advice on driving habits. Using this system can save 15% in fuel consumption (Reichart).

Current patents include: vehicle navigation system, route selection apparatus, and land vehicle multiple navigation route apparatus. The vehicle navigation system includes map memory for storage of road map information and target data memory along with a position detector to determine the present position of vehicle (Ito and Nimura, 2000). The route selection apparatus for motor vehicles with an energy storage device contains a data input unit, a road network memory for storing locations, a computer unit for determining multiple route to get to the same destination including energy supply process, the energy supply network and the route specific energy consumption. It also has a display for routes (Boll and Buck, 1998). The land vehicle multiple navigation route apparatus has a road network memory and is used by a computer unit to give optimal routes based on input. Optimal routes are found with respect to distance to be covered or travel time. It offers multiple navigation routes to get to a certain destination. The driver is then guided to their destination through the display screen (Kirson, 1993).

Given the information on benchmarking and literature review, there is currently no product available that determines the optimal route based on minimal fuel consumption and navigates

that route in the user's vehicle. There are currently only navigation systems and method of reducing fuel consumption based on driver habits. The vision of this project will be to bridge this gap between navigation systems and optimal route based on minimal fuel consumption.

5.0 Customer Requirements and Engineering Specifications
The main customer requirement of this project was to provide the user with the most fuel efficient route to a destination, then relay that route to the driver via a navigation system. The scope of this project has been narrowed to provide a proof of concept for this system. This proof of concept will included generating a model that will predict fuel efficiency in a single case study. The proof of concept also included a trip analysis program that will analyze data recorded from the OBDII port of the vehicle during a test run of the optimized route. Our engineering team has translated the customer requirement of finding the most fuel efficient route to a destination into proof of concept engineering specifications:

List of Engineering Specifications:

Case Study Model
- Will quantitatively predict the route of least fuel consumption
- Will evaluate two routes, then find the one of least fuel consumption
- Will use energy equations to estimate fuel consumed on each route, then multiply that energy by an initial vehicle efficiency and convert that energy into gallons in order to predict the route of least fuel consumption
- This model will be verified using the Auto Tap program
- After the model is informed, if the route proves to be inferior, a new path will be determined.
- Once the program is informed, fuel consumption for a third route will be determined.

Post Travel Analysis Program (Feedback)
- Will have a graphic user interface (GUI) programmed in C++
- Must read Excel spreadsheet generated from Auto Tap hardware during actual test run of optimal route found by the navigation program (this spreadsheet will include instantaneous miles per gallon data, throttle position, brake position)
- Will report fuel consumption, time of trip, driving habits to user via GUI and suggest better habits for future trips
- Save trip data to user profile to archive changes in user habits
- Program will assume that vehicle mass and driving conditions (weather) are similar for each route

Routing Program
- Must have a GUI
- Must generate a profile for users that includes driver's name, vehicle type, time of day and day of week (this information will be stored in a database for later driving habit analysis)
- Must take input of starting location, destination, time of day and day of week.
- Will return text based driving directions as well as a data file of directions to be read by vehicle navigation program.

- Driving directions will be given to minimize fuel consumption based on the following criteria: distance, known construction, traffic congestion, speed limits, number of traffic control devices (stop lights, stop signs, and yield signs).
- Prompt the user for approval of route before loading to car.

6.0 Concept Generation
Based on our customer requirements, concepts were developed for the home computer and the in-vehicle hardware.

Home Computer
The computer will find an optimum route by minimizing fuel consumption. Factors that effect the fuel consumption are number of stops, distance, driving habits, elevation changes, construction, traffic congestion, speed limits, and weather. An initial idea was to choose a route with the fewest of these factors that impact greater fuel consumption. Expanding on this idea, the route would be broken up into segments and nodes. The idea was that a node would be between each segment. Ideas for where the nodes would be located were at traffic lights and stop signs; at any change in acceleration or possible change in direction.

Two ideas were generated for comparison of different routes. The first idea was that each segment of road will have a fuel efficiency value (FEV) associated with it. Each traffic regulation (speed limit, distance, stop sign, yield sign, traffic light) will be given a FEV number. We will then sum these numbers of each segment along each route and select the route with the smallest total. The second idea was to make a prediction of fuel used for each segment and node. Then, sum the amount of fuel used on all route being considered and the route with the lowest gas consumption will be the route presented to the driver.

In-vehicle Hardware
Another requirement was to have a navigation system in the car. For the display of the map and directions a PDA, laptop, LCD screen, and using previous in vehicle navigation display were considered. After the display is chosen, the idea was to download the map wirelessly or through a PDA or laptop. Also effecting the decision of the display is that the vehicle must be Global Positioning System (GPS) enabled in order to give directions to the driver. Several ideas were generated for how the information would be displayed.

One of our customer requirements was a device letting the driver know when to turn. The first idea was based of the design process football shown in Appendix C on page 23. Different lights of the football would mean different directions, such as straight, slight or hard turn. The second idea was to connect to the turn signals, but have different color lights to represent advice. The third idea was to have plain arrows that lighted up shown in Appendix C on page 23. The last idea was to have an arrow on the map that would change colors and blink, to notify driver, shown in Appendix C on page 24. Also the idea of giving audio prompts to the driver was considered. The idea was to give directions through the vehicle speakers or wireless Bluetooth earpiece.

The next part of the design was determining how gas consumption and feedback would be recorded for each trip. First we wanted to get data on distance, time, air to fuel ratio,

acceleration, and deceleration to properly assess fuel used and driver habits. The idea for getting these factors was to look at power train data. This can be done through the OBD II port, which is usually located under the steering wheel. The OBD II port reads power train control data, including instantaneous air/fuel mixture. Software on the market is readily available that can store the data read from the OBD II port though USB connection to a computer, which outputs the data in Microsoft Excel Spreadsheets.

For computing actual fuel used two ideas were generated. An initial idea was to compute the instantaneous fuel consumption through a volumetric analysis of the engine, and uses this volume in a calculation using the speed of the engine. The other idea was to use software that stores information from the OBD II port.

We found that driving habits have a great impact on fuel consumption. Next, a list was generated of possible feedback that should be given to the driver. Feedback discussed was creeping, hard acceleration, cruise control, deceleration/acceleration frequency, optimal speed for most efficient fuel consumption and changing lanes. All this information would be provided from analysis of power train control data.

To better assess each driver, the idea for a user profile was generated that would include identification (name), type of vehicle, time of day, age, sex, weather and driver classification (ex. slow and cautious driver). Having this profile would be used for updating information on routes previously driven and help future drives. The idea to help other drivers was formulated so that if drivers had similar profiles for a certain route, someone could go online and find the most fuel efficient route for them. Ideally a database with information on routes driven in terms of fuel consumption and time would be implemented.

7.0 Concept Selection
To find the optimal route, factors considered are number of stops, distance, speed limits and traffic congestion. These factors were chosen because of their feasibility to quantify their effect on fuel consumption.

To predict each factor's effect on fuel consumption, each route will be broken into segments and nodes. Each node represents an acceleration/deceleration zone (stop signs, traffic lights, and expressway exits). Each segment and node will be given a value of fuel consumption, which is better than the FEV method because it can similarly predict one route being more fuel efficient than another, yet can also predict fuel consumption of future routes. All nodes and segment values of fuel used will be summed. The route that uses the least amount of fuel will be provided to the driver. From there the driver has the option to accept or decline this route based on the amount of time to take the given route. If the driver wishes not to use the route with the least amount of fuel used, a route will be provided that takes less time and not as eco-friendly. We chose to use this strategy rather than pick a time cut-off because driver opinions will vary on amount of time versus fuel consumed. The reason we decided to suggest a second route if the user rejects the first is that we believe that the more versatile the program is, the more people it will appeal to, and thus the market will be increased for our product. In addition, if we don't provide an alternate route, the user will have to look on an online website such as Mapquest ©

anyways to get a route, which will take even longer than if we had just recommended a second route to begin with.

After the route is provided the computer will transmit the route to the vehicle via wireless connection. This method was chosen assuming the car is equipped with an in-vehicle display and has wireless internet or Bluetooth connectivity. This method for transmitting route information was chosen due to ease on the user. The route will then be provided on the in-vehicle display and will be synched up with the in-vehicle Global Positioning System (GPS), again this assumes the vehicle is equipped with GPS. We chose to download the route and provide it on the in-vehicle display rather than a PDA for several reasons. First, it is much simpler to have it done wirelessly right to the car. Second, the displays in the dashboards of many cars today are often bigger than PDA screens, making the viewing easier. Ideally, the car will compute the fuel consumption automatically. If it does not do this automatically, then the user will have to purchase software like AutoTap to calculate it.

Directions will be given to the driver through auditory and visual prompts. To promote heightened driver awareness, auditory prompts will be given to the driver to prevent the driver from looking at the screen. The auditory prompts will be given through in-vehicle speakers to minimize additional hardware. The Bluetooth earpiece was not chosen mainly because it is a driver distraction. The visual display will be included to help the driver with unfamiliar territory. The visual display was chosen based on the list of pros and cons of each concept, shown in Appendix C. The final concept shown in Appendix C was chosen due to simplicity and easy to understand by drivers and ability to program lights.

The next part of the design was determining how gas consumption and feedback would be recorded for each trip. Fuel consumption was initially though to be calculated using the method in Appendix E (actual method used is shown in Section 10.0 Prototype). The reason for choosing the AutoTap software is because it records to an easy format in a Microsoft Excel Spreadsheet, which can readily be used in writing a program in many different languages to determine the necessary feedback to the driver. Other software like AutoTap is available on the market, but this software was chosen due to its availability. Specifically, we chose the AutoTap version for General Motor vehicles because this software was readily available and we have access to a General Motors vehicle. The methodology could be applied to all vehicles given that there is software that stores information about powertrain.

Factors chosen to be analyzed for feedback on driving habits are hard acceleration, creeping, and use of cruise control. Hard acceleration is defined when the engine RPM exceeds 4500. Creeping is slowly advancing by small increments at a light. Cruise control should also be used whenever staying at a constant velocity above 55 MPH. These were chosen because acceleration is the main impact on fuel consumption. Also, this is the only available data that can be gathered from the AutoTap software. Braking pedal position and steering wheel angle position are not available on AutoTap.

To better asses each user the driver will enter their name, type of car, and time of day for each route. After entering all this information this will be saved to a personal and online database that will include these factors along with actual fuel consumption and time of route. The driver will

be given the option to put their data online due to privacy issues. Both databases will be used to update fuel of each segment and node for determining optimal route.

Determining the specific coding language was also a criterion. For the user interface, model and driver feedback coding will be done in C++. This was chosen because of the familiarity with this language by the entire team and compatibly with Microsoft Excel.

Due to time constraint and limited programming knowledge of our team we have scaled our project to generate a proof of concept. The vision of the project is shown above and is outlined in Appendix A on page 22. The scope of this project is to focus our efforts on finding the optimal route and driver feedback. The next section gives details about what the scope of our project focused on.

8.0 Final Design
The basis of our final design was a model that will predict fuel consumption for any route and give feedback to the driver. In order to make the model we defined each segment and node within our selected region with a fuel consumption value, then validated if the amount is correct for each and last inform our model. Then the informed model will be able to make predictions on future routes. We then showed how the model works by performing these steps for two different routes.

The two routes chosen to be analyzed are shown in Figure 1 below. The starting location was 3500 Plymouth Rd and the end location is 2608 W Liberty St. The reason for choosing these locations was so both highway and city roads could be analyzed. The red route represents the route Mapquest© suggests. The blue route represents the city route that Mapquest© suggests to avoid highways.

Figure 1: Map of highway and city routes

Each route was broken into segments and nodes, based on possible change in acceleration at turns, stop signs, traffic lights, and expressway exits. As shown in Figure 2, a node represents acceleration and segment represents constant velocity. The reason for splitting the route into segments and nodes was to give a better estimate of fuel consumption and looking at points (nodes) that consumed the most amount of fuel (during acceleration). Nodes and segments will also be given a definition to help predict routes in the future. The definition will include distance, traffic flow and speed limit. Traffic flow will be taken into account by time of day, for this project we had rush hour and non-rush hour traffic.
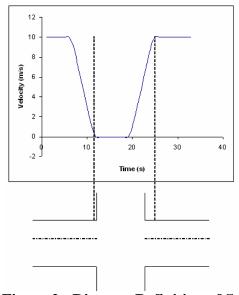

Figure 2: Distance Definition of Segment and Nodes

To serve as a baseline for defining each segment, energy equations will be employed to find the total energy used on each node and segment. We also divided the calculated energy by an initial vehicle efficiency factor of 15% to estimate energy used, and then convert this energy into gallons of regular unleaded fuel.

These baseline segments and nodes will then be compared with actual fuel consumption. The actual fuel consumption will be found for each segment and node using equations shown in Section 10.0 Prototype. To get all the necessary information in order to calculate instantaneous fuel consumption, data will be stored using the AutoTap software as previously outlined in the concept generation section. The AutoTap software will then export to Excel spreadsheets. The information necessary to compute the instantaneous fuel consumption are: injector pulse width, mass airflow sensor, air/fuel ratio, number of cylinders, and the revolutions per minute, obtained from AutoTap. Since we are using a Pontiac Grand Prix, the number of cylinders will be six, as shown in the derivation of our instantaneous fuel consumption.

After this has been completed for each segment and node the baseline will be compared to the actual fuel consumed. If the baseline is within 10% of the actual fuel consumed the model will not be informed. If the model in not within 10% we will adjust the vehicle efficiency accordingly.

This informed model can then be used to predict future routes that have not been driven. Prediction of route that has never been driven must be broken up into segments and nodes and have a good estimate of the factors in the definition (distance, traffic flow and speed limit).

9.0 Engineering Design Parameter Analysis
The alpha prototype for this project consists of a fuel consumption model of a portion of Ann Arbor. In order to predict the route of lowest fuel consumption, an optimization method must be chosen. An expedient method of minimizing fuel consumption is to break down the section of a road map into segments and nodes. Each node is an intersection and the roads connecting these nodes are segments. This definition of a node allows each node to have a deceleration and acceleration, and thus can easily incorporate the kinetic energy equation.

In order for this approach to be useful, each node and segment must be characterized. Our team has chosen to record the speed limit, length, and traffic flow (by time of day) for each segment and node. These characteristics were chosen because they are most closely tied to the acceleration of the vehicle, which is a major contributor to poor fuel economy. Once each node is characterized, we will find actual data about fuel used on each segment and node. This method was selected because known information about fuel consumption on characterized nodes and segments will be assumed equal to similar nodes and segments. This allows the model to predict fuel consumption on nodes and segments that have not been actually tested.

The model will make an initial guess at fuel consumption used by employing equations of motion. Once the routes are broken up into nodes and segments, different equations will be used to calculate the energy used on each node and segment. These equations use velocity, drag coefficients, mass of the vehicle, and friction coefficient of the tires. The segments will employ equations that calculate the energy used while cruising at a given velocity. The nodes will use equations that calculate energy used while accelerating. After the energy is theoretically calculated, we will divide each energy total by 15% as an initial efficiency factor. We will then convert this energy used into gallons of fuel by using known information on how much energy is contained in one gallon of regular unleaded fuel. Once we have the efficiency adjusted fuel consumption for each node and segment along the route, we will choose the route with the least amount of fuel consumed. After the route is chosen, we will drive the initial route and compare the fuel used on that route compared to alternate routes. This testing will also allow the system to be adaptive insofar as evaluating the efficiency of the vehicle.

During the test drive of the initial route, fuel consumption information will be generated for each segment and node encountered on the test. This data set will give us the capability to calculate an actual efficiency for a given node or segment. If this actual efficiency is outside of a 10% tolerance of the assumed initial efficiency, we will adopt the actual efficiency as the new efficiency for that type of node or segment. This will give the model a more accurate prediction for fuel consumed on similar (same distance, speed limit, and traffic flow) nodes or segments in the future.

This system will allow the model to predict the route of least fuel consumption because each segment and node will have a given fuel usage associated with it. From that point on, it is simply a matter of summing up fuel usage for numerous routes from point A to B, then selecting

the route of least fuel consumption. This may be viewed as the "brute force" method, but is quite robust. Once routes and segments are characterized, the fuel consumption associated with them may be applied to other similar un-tested segments, so that fuel consumption may be found and minimized on future routes.

10.0 Prototype

In order to make a proof a concept, the design was tested from a start and end location. Two routes were chosen in order to calibrate the model, which are shown in Figure 1 on page 10. This model was developed on a 2000 Pontiac Grand Prix GT.

Each route was broken into segments and nodes. To determine distances for each segment and node each route was driven and distance was recorded at each nodal location by the odometer, see Appendix F for locations of nodes. To determine the distance of each node, the kinematic equation shown below in Equation 1 was used. The velocities that were used are based off of speed limits. The acceleration from a node was assumed to be 2.5 m/s^2. This is a moderate acceleration ensures comfortable acceleration that does not exert a large force on passengers or drivers.

$$d = \frac{v_f^2 - v_i^2}{2a} \qquad \text{(Equation 1)}$$

Segment distance was found by taking the distance between each stopping intersection and subtracting the node distance. Appendix G shows the distances for each segment and node. Equation 2 shows the energy for each segment (constant velocity). Equation 3 shows the energy used for a node (acceleration) (Rubin, 2001). Where the drag coefficient, C_d, is .4(Gillespie, 1992), the frontal area, $A_{frontal}$, is 2.82 m^2, the density of air, ρ_{air}, is 1.2 kg/m^3, the weight of the vehicle, $W_{vehicle}$, is 15068 N, d is the distance for the segment or node, v is the velocity (speed limit), a is the acceleration, and the acceleration of gravity, g, is 9.81 m/s^2. It was assumed that drivers stopped at every node.

$$E = (.5 * C_d * A_{frontal} * \rho_{air} * v^2 + C_d * W_{vehicle}) * d \qquad \text{(Equation 2)}$$

$$E = (a/g) * W_{vehicle} + C_d * W + .25 * C_d * A_{frontal} * \rho_{air} * v_{final}^2) * d \quad \text{(Equation 3)}$$

Each segment and node energy was divided by an initial efficiency of 15%. The energy was then converted into fuel consumed using Equation 4. The energy of gasoline, $E_{gasoline}$, is 1.33 x 10^8 Joules/gallon.

$$Fuel = \frac{E}{E_{gasoline}} \qquad \text{(Equation 4)}$$
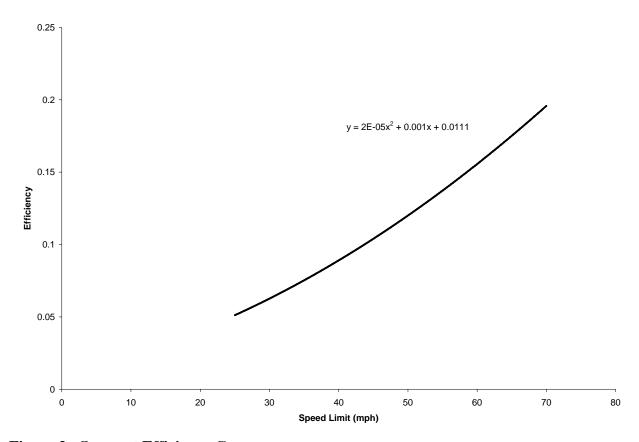
Then the two routes were driven to find instantaneous fuel consumption using the AutoTap software. The equation for instantaneous fuel consumption is shown in Equation 5. The density of gas, ρ_{gas}, is 0.703 g/ml.

$$Gas\ Consumption\ (gal) = \frac{Mass\ Air\ Flow}{(Air : Fuel\ Ratio) * (\rho_{gas})} * \Delta Time \qquad \text{(Equation 5)}$$

The distance for each segment and node for AutoTap was found using Equation 6.

$$Length\,(mi) = Vehicle\ Speed * \Delta Time \qquad \text{(Equation 6)}$$

After the actual fuel consumption was found it was compared to the initial fuel prediction. It was found that the initial fuel prediction, with efficiency of 15%, was not within 10% of actual fuel consumed. We then assumed 100% efficiency from the energy equation in order to find the actual efficiency. These efficiencies were then averaged together for a certain speed limit. For nodal efficiency outliers were taken out before averaging.   These efficiencies were then plotted against speed. A best fit line was found for each segment and node shown in Figure 3 and 4 respectively.

$$y = 2E\text{-}05x^2 + 0.001x + 0.0111$$

Figure 3: Segment Efficiency Curve
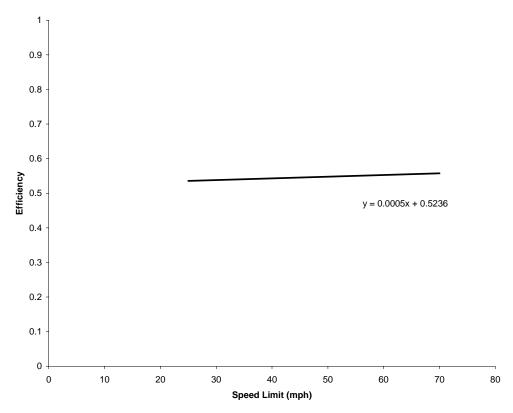
Figure 4: Node Efficiency Curve

The equations shown in Figure 3 and 4 were then used as the new efficiencies. This method was done for non-rush traffic flow. There would be different efficiency curves for different traffic flows (time of day). Appendix G shows the segment and node distance, speed limit, initial prediction and actual fuel consumption for both routes used for calibration.

11.0 Validation and Test Results
After the model was constructed, the model had to be validated for instantaneous fuel prediction calculated through use of AutoTap and validating that the calibrated efficiency curves were accurate in predicting fuel on unknown routes.

Validation of Instantaneous Fuel Consumption
In order to assess if the instantaneous fuel consumption (Equation 5) found by using data from AutoTap was accurate, the vehicle initially had a full tank of unleaded gasoline. AutoTap then recorded PCM data for a given trip. After the trip, the tank was then refilled and the amount of gas added after the trip was recorded. This number was then compared to gas consumed using the instantaneous fuel equations. It was found that the instantaneous fuel equations yielded a 2% error when compared to actual fuel consumed. This proved that the use of AutoTap and Equation 5, accurately determines instantaneous fuel.

Validation of Predictive Model

To validate the model, we applied the fuel consumption calculated for the segments and nodes to predict a route that would yield the lowest gas consumption. Using the calibrated model, we predicted the fuel consumption for two new routes from the beginning to end point. One route was primarily city driving and the other was mainly highway. These two routes are shown below in Figure 5. The green route represents city driving whereas the gray is highway.

Figure 5: Routes used for Validation

The predicted fuel consumed using calibrated model on these two routes is given in Table 1 below. Appendix H shows the segment and node distance, speed limit, initial prediction and actual fuel consumption for both routes used for validation.

Table 1: Predicted and Actual Fuel Consumed on Validation Routes

	Actual Fuel Consumed (gal)	Initial Fuel Consumption Prediction	Initial % Difference	Calibrated Fuel Consumption Prediction (gal)	Calibrated % Difference
Gray (Possible Route 4)	0.510	0.629	23.378	0.552	8.325
Green (Possible Route 4)	**0.399**	**0.419**	**5.057**	**0.417**	**4.531**

As seen in the table, the model predicted the green route to be the most efficient of the two validation routes. Both predictions were within 10% of the actual fuel consumed on the route. Table 1 also shows that the calibrated model predicts fuel consumption more accurately than the initial prediction of 15% efficiency. This shows that Eco-Route will be able to predict the most fuel efficient route.

Segment and Nodal Analysis

Our method of breaking the route into segments and nodes worked over the course of the route, but was not entirely accurate on a per-segment basis. A large deviation between the actual and predicted fuel consumption was found for the individual segments as seen in Figure 6 on page 17. Our data also showed a large variation in actual efficiencies due to driving variables like traffic, varying acceleration, erratic drivers, etc. Our model takes into account these differences by averaging all efficiencies for each speed. When lumped by specific speed segments, the

predicted fuel consumption was very close to actual consumption as shown in Figure 7. Some of the error in fuel consumption is due to AutoTap. It was also hard to precisely define a segment or node in the AutoTap data, this contributes error to the calculations.
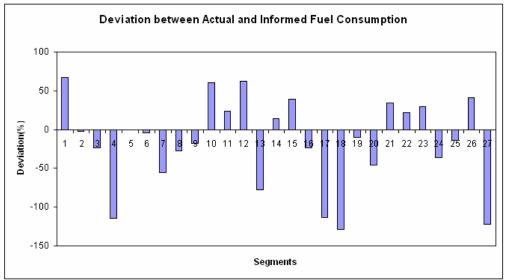
Figure 6: Deviation between Actual and Informed Fuel Consumption for Route 3(Green)
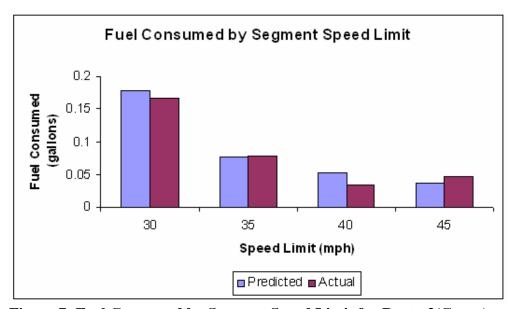
Figure 7: Fuel Consumed by Segment Speed Limit for Route 3(Green)

The deviation trend also holds true for the nodes within the route. The probability of stopping at a light was not taken into account in our model, which could cause a difference in fuel consumption. This was due to the fact that our model cannot know the exact light program, preventing its capability to predict probability of stopping. This in mind, our model assumed the driver stopped at every light.

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12.0 Discussion

We recognize that our design has room for improvement. One of the things that we would change would be to improve how we measure and divide up the segments and nodes. The method that we used was to measure the distances using the cars odometer. This only had a resolution to the tenth of a mile. We recognize that a better resolution would yield distances that were more accurate. We noticed the repercussions of this inaccuracy when we went to analyze our data. We noticed that the data corresponding to distances obtained from AutoTap were sometimes off by a few meters from the distances given by the nodes and segments. While our routes were not long enough to have this effect have a noticeable impact on the outcome, we foresee this as a possible problem on longer routes.

Another weakness in our model is the extent to which we tested it. We tested the predictive part of our model during non-rush hour traffic conditions, because of time constraints. While this is not ideal, we think it validates the rush-hour portion of our model because it is the same theory, just different values for efficiencies.

An improvement that we would make to our model is the addition of elevation change to the energy equations. Our team recognizes that climbing up a hill will consume much more gas than a flat road or going down hill. We did not include this for our project because it was outside the scope of our project and would involve synching up our segment and nodal map with an elevation map. Another reason that we did not include it in our model is that Ann Arbor is a fairly flat area and thus we did not see elevation change as a major factor in fuel consumption. If this were to be done on a broader scale, then elevation change would definitely have an impact and would need to be accounted for.

13.0 Energy and Environment Impact Analysis

A program such as Eco-Route has the potential to make a great impact on the environment. Currently a quarter of the pollution in the world is produced in the United States, a third of which is contributed by automobiles. With the implementation of Eco-Route, these numbers can be greatly reduced.

In our analysis, we simplified the gasoline combustion equation to:

$$2C_7H_{14} + 21O_2 \rightarrow 14CO_2 + 14H_2O.$$

Performing the stoichiometric analysis, we determined 98g of gasoline to produce 308 g of Carbon Dioxide.

Upon driving the original route determined from Mapquest© (red route), we found the trip's fuel consumption to be roughly 0.45 gallons. This produces 3763.62 g of Carbon Dioxide, as shown in the following calculation:

$$.5 \text{ gal} * 3785.4118 \text{ mL/g} * .703\text{g/mL} * 308\text{g } CO_2/98\text{g Gas} = 3763.62 \text{ g } CO_2$$

Once our model was informed and Eco-Route determined an optimal route for fuel consumption, we drove the route and found our fuel consumption to be 0.29 gallons of gas. This shows a fuel

savings of 0.16 gallons. With this fuel savings comes a reduction of 1338.18 g of Carbon Dioxide, as found using the equation above. This presents a reduction to both fuel consumption and Carbon Dioxide by 35.6%.

14.0 Personal Impact
Such a significant savings appeals to many groups of people. If the average person were to utilize Eco-Route in their daily living, a large monetary benefit is attainable. On average, people put 1000 miles on their car in a month. Assuming an average gas mileage of 20 miles per gallon and fuel price of $2.297/gallon (Energy Information Administration, 2006) this comes to a monthly expenditure of $114.85 and $1378.20 annually. Upon purchasing Eco-Route and implementing it in their daily driving, these numbers reduce to expenditures of $73.96 monthly and $887.56 annually. This presents an annual savings of $490.64.

If monetary gain does not appeal to people, they can focus on the environmental savings that Eco-Route produces. If everyone in the United States were to utilize Eco-Route, the 33.3% pollution production percentage in the United States from automobiles would drop to 21.5%. Worldwide, US automobile pollution production would drop from contributing 8.33% to producing 5.37% of the pollution. In a society where the environment is being depleted by its residents, Carbon Dioxide reduction would be extremely advantageous. The greenhouse gas reduction would help deter solar radiation from reaping its numerous damages.

15.0 Recommendations
With the objectives achieved from our project, we have several recommendations as to the future of Eco-Route and its implementation in current society. First, for the program to work best, a map of the United States should be divided into segments and nodes. Segments with different elevations and turns will be included in this assessment to better inform the model. This process could be completed by Ford and then stored within the algorithm.

Another effective step in Eco-Route's advancement would be to calibrate the efficiency of the vehicle Eco-Route will be used with using Powertrain Control Module (PCM) data that is recorded for a week. This would allow the calibration to cover various speeds and times of day the various driving will take place. This will enable a better production of the informed model. To make the program most applicable to the specific user, this should be done after the system's purchase to characterize the driver's habits and apply it to the efficiency mentioned earlier. The system would then be able to recalibrate every six months to allow for driver adjustments and improvements. Upon every calibration the driver would receive feedback (see Appendix D) on how to improve their fuel consumption. To make the system applicable to more than one user per software purchase, the user will have a sign in name to access his/her personal Eco-Route information. To provide for maximum efficiency the algorithm and calibration should be done within the vehicle from the PCM data. The information (efficiency curves, driver recommendations, etc.) would then be sent wirelessly to a home computer.

By completing the steps above, Eco-Route will be capable of predicting fuel consumption for all segments and nodes in the United States. It will then use this information to sum up gas consumption over various segments and nodes to determine the optimal route between two locations and communicate fuel consumption information and travel time to the user for the

specified route. This will allow each individual user to determine weigh whether the difference in fuel consumption is worth the possible extra time spent and accept or decline the proposed route. If the user decides to deny the proposed route they will be given the path that requires the least amount of time. Once Eco-Route becomes widely used, a database should be created to house the various fuel efficient routes for other users to view and analyze.

The other part of our design is give driver feedback on driving habits. This will be done since changing driving habits can significantly lower fuel consumption. The different factors and prompt that will be given to user after trip are outlined in Appendix D. The program will also output to the user time of trip, and fuel consumption.

16.0 Conclusions

After our testing and validation, Eco-Route is capable of determining gas consumption for a specific route within 10% of actual. From our highway and urban routes, we generated an accurate efficiency curve that applies to a specific time of day. These findings were validated for both routes by using our model to predict fuel consumption for each route and then physically driving the route. Using AutoTap, we measured the various engine parameters recorded by the car's Powertrain Control Module (PCM) to calculate fuel consumption. This method of incorporating the PCM data to determine calculations was found to have only a 2% error, showing to be very accurate.

All of these factors show how Eco-Route accurately measures fuel consumption. Using this capability, it is able to predict the route of lowest fuel consumption. Our model led us to find a route (route 2-blue) that saved .16 gallons of gas per trip compared to the route suggested by Mapquest©. We can then project this case to the situation where the user is using this route to drive to work every day, 5 days a week, going directly to and from work. In this case the driver would save 78 gallons of gas annually, projecting to an approximate cost savings of $195.

These tasks are all accomplished using existing measurements, leaving the only cost for Eco-Route's functionality to be the price of AutoTap, assuming the user already has a laptop. Minimal energy is used in the process as minimal energy would be required to download the optimal route from the laptop.
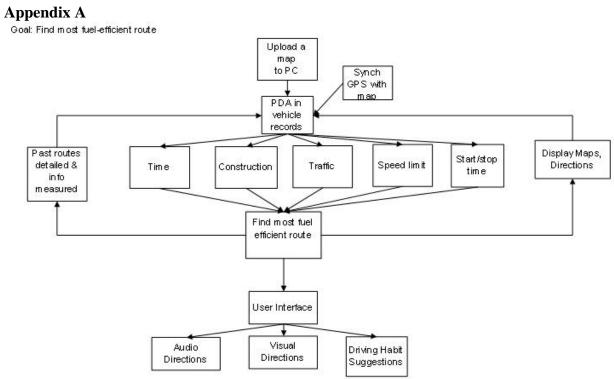
17.0 Acknowledgements

We would like to thank our sponsor and professor, Steven Skerlos, for supporting our team throughout the semester.

18.0 References
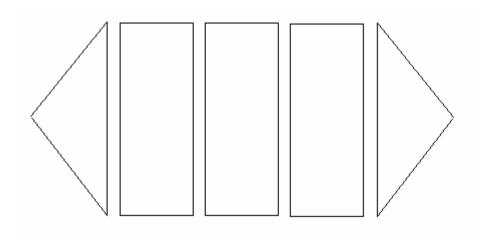
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      ml

Appendix A

Goal: Find most fuel-efficient route
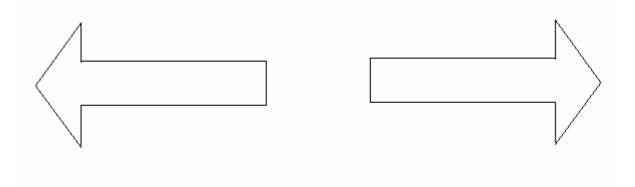
Figure 1: **Energy Conservation System Process**

Appendix B

Design #1 - Football Light

Design # 2- Plain Arrow
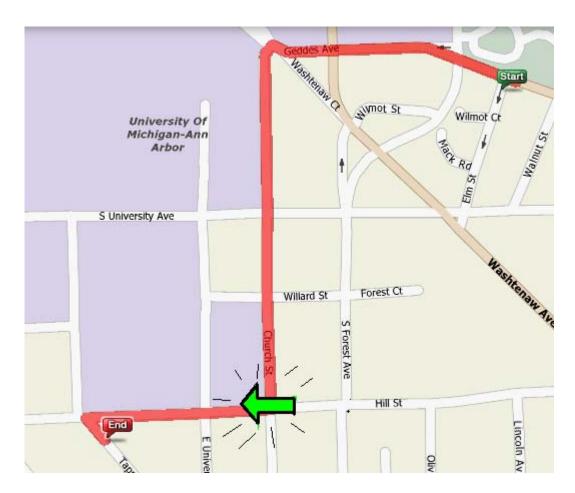
Figure 5: Design #3- Arrow Flashing on Map

Appendix C

DESIGN	PROS	CONS
Design #1 (Football Lights)	Simple	For outer middle lights driver might get confused that it is slight right since block is straight
	Can Differentiate from Going Straight, Slights Turns or Hard Turns	Will always have a light on since straight light, driver might not notice change to turn
Design #2 (Turn Signal)	Driver will easily understand when to turn since familiar with turn signals	Driver might not actually put on turn signal
		Difficult to wire
		Navigation system would be more complex to install
Design #3 (Plain Arrows)	Easy to understand by driver	Driver might be confused with turn signals, since similar appearance
	Will easily be able to notify when turn is approaching	
Design #4 (Arrow Flashing on Map)	All on one unit	Hard to read
	Driver already paying attention to map, so it would limit number of distractions	

Table 1: Pros and Cons of Different Design Ideas

Appendix D

Feedback prompts to user:

All prompts will come up if problem occurs more than three times throughout the course of the route, because three times defines that it is a habit.

Problem: Creeping
Throttle position doesn't change but then decelerating during a period on X ft.
Prompt: Do not creep up to drivers in front of you

Problem: Hard accelerating
Acceleration greater than 4000 rpm
Prompt: "Do not accelerate so hard"

Problem: Cruise Control
For over three miles, going over 55 mph and varying between +/- 2.5 mph.
Prompt: "Use cruise control when applicable"

Appendix E
Calculation of instantaneous fuel consumption

Mass air flow: amount of air that enters into the engine [grams/sec]
Air Fuel Ratio: Percent of air to fuel [%]
Injector Pulse Width: Time fuel injector is fired [ms]

(1) $\dfrac{Mass\,Air\,Flow\,Per\,Cylinder}{Air\,Fuel\,Ratio} = $ Amount of fuel used per second per cylinder [g/s] per cylinder

For our case we did all of our calculations using a car that had 6 cylinders so (1) then becomes:

(2) $\dfrac{Mass\,Air\,Flow\,/\,6}{Air\,Fuel\,Ratio} = $ Amount of fuel used per cylinder [g/s] per cylinder

If we multiply (2) by the injector pulse width we will obtain the amount of fuel used per cylinder per revolution of the engine (shown in equation (3)).

(3) $\dfrac{Mass\,Air\,Flow\,/\,6}{Air\,Fuel\,Ratio} * PulseWidth$ [Milligrams per revolution of the engine]

If we divide (3) by the density of gas (0.703 grams per milliliter, taken from US Dept. of Transportation) we obtain the Volume of gas used per cylinder per revolution of the engine.

(4) $\dfrac{\dfrac{Mass\,Air\,Flow\,/\,6}{Air\,Fuel\,Ratio} * Pulse\,Width}{0.703}$ = Volume of Gas used per cylinder per revolution of

the engine. (micro liters per revolution) [μL per revolution]

If we multiply (4) by the number of cylinders and then again by the tachometer reading (revolutions per minute) we obtain the volume of gas used per cylinder as a function of time.

(5) $\dfrac{\dfrac{Mass\,Air\,Flow\,/\,6}{Air\,Fuel\,Ratio} * Pulse\,Width}{0.703} * 6 * \dfrac{Re\,volutions}{Minute}$ = Volume of gas used in the entire

engine as a function of time [μL/min].

This time can then be converted to any time scale that we want (seconds or milliseconds) depending on how we want to use it.

Appendix F
Table 2: Location of nodes for each route

1st route-Red	2nd route-Blue	3rd route-Green	4th route-Grey
Southbound exit ramp light	Green Light	Green Light	on 23
Start of on Ramp of US 23-N	Huron Pkwy Light	Huron Pkwy Light	light off 23
US 23 N(end of on ramp)	Nixon Light	Hubbard	Arborland
End of curve onto M-14 W	Traverwood Light	Glacier Way	Light
Start of 23 to M-14 curve	Murfin(Upland) Light	Fuller	Huron Pkwy
end of ramp 23 to M14	Barton Dr.	Bonisteel	Sheridan
exit at Maple from M-14(beginning of exit)	Broadway	Cedar Bond	Bedford
Stop sign off M-14(end of exit ramp)	Monroe	E. Medical Ctr	St. Francis
Miller Light	Swift	Fuller	Brookman Blvd
Dexter Light	5th	Catherine	Packard
Maple Village Plaza Light	Main St.	Ann	Henry
Jackson Light	Miller	Huron	Main
S. Maple light	Ann	State	S. Seventh
Liberty Light	Huron	Division	Pauline
	Washington	N. Fifth	Federal/Arbordale
	Liberty	Fourth	Liberty
	Ashley	Main	Maple
	1st	Ashley	
	3rd(Stop Sign)	First	
	7th	Washington	
	Virginia	W. Liberty	
	Stadium Blvd	Third(Stop Sign)	
	Maple	Seventh	
		Virginia(yellow light)	
		Stadium	
		S. Maple	

Appendix G
Table 3: Segment and Node Fuel Consumption for Route 1(Red)

Segment	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Actual Fuel Consumed(gal)
1	45	0.15	0.005435198	0.020865769
2	70	0.199708	0.012323988	0.007318535
3	70	0.128597778	0.007935774	0.013569509
4	70	1.3	0.08022305	0.060490953
5	70	2.1	0.12959108	0.086679704
6	55	0.5	0.022547829	0.023904355
7	55	2.7	0.121758275	0.100937911
8	55	0.3	0.013528697	0.013053961
9	35	0.324872444	0.009468684	0.009436564
10	35	0.619576444	0.018058083	0.028366519
11	35	0.119576444	0.003485157	0.003853163
12	35	0.169576444	0.00494245	0.01467422
13	35	0.069576444	0.002027865	0.001059683
14	35	0.369576444	0.01077162	0.020664734
15	35	0.069576444	0.002027865	0.001251045
		Total:	**0.444125617**	**0.406126625**

Node	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Actual Fuel Consumed(gal)
1	45	0.050292	0.016999668	0.003804679
2	70	0.071402222	0.02504483	0.002833185
3	70	0	- - -	- - -
4	70	0	- - -	- - -
5	70	0	- - -	- - -
6	55	0	- - -	- - -
7	55	0	- - -	- - -
8	55	0.075127556	0.025727418	0.008684751
9	35	0.030423556	0.010175916	0.006545115
10	35	0.030423556	0.010175916	0.004919849
11	35	0.030423556	0.010175916	0.006418241
12	35	0.030423556	0.010175916	0.001994827
13	35	0.030423556	0.010175916	0.006234352
14	35	0.030423556	0.010175916	0.00359241
		Total:	**0.128827412**	**0.045027409**

Table 4: Segment and Node Fuel Consumption for Route 2(Blue)

Segment	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Actual Fuel Consumed(gal)
1	45	0.1	0.003623465	0.011953353
2	45	0.549708	0.019918479	0.025206095
3	45	0.099708	0.003612885	0.004995469
4	35	0.199708	0.00582066	0.006296336
5	35	0.369576444	0.01077162	0.011574147
6	35	0.669576444	0.019515376	0.025553532
7	30	0.519576444	0.013647208	0.014663733
8	30	0.027648	0.000726203	0.002104245
9	30	0.077648	0.002039504	0.00436544

Node	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Actual Fuel Consumed(gal)
10	30	0.377648	0.009919312	0.015196244
11	30	0.127648	0.003352806	0.00689994
12	30	0.077648	0.002039504	0.009771363
13	25	0.027648	0.000658831	0.00283044
14	25	0.084477778	0.002013042	0.007643733
15	25	0.034477778	0.00082158	0.001980869
16	25	0.034477778	0.00082158	0.00252859
17	25	0.034477778	0.00082158	0.00167708
18	25	0.034477778	0.00082158	0.004138733
19	30	0.134477778	0.003532197	0.012246823
20	30	0.227648	0.005979408	0.016977659
21	30	0.427648	0.011232614	0.020892168
22	30	0.527648	0.013859216	0.034328224
23	30	0.077648	0.002039504	0.006293741
24	30	0.127648	0.003352806	0.003477453
		Total:	**0.140940961**	**0.253595409**

Node	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Actual Fuel Consumed(gal)
1	45	0.050292	0.018806252	0.003626882
2	45	0.050292	0.018806252	0.004970248
3	45	0.050292	0.018806252	0.001805795
4	35	0.030423556	0.010837036	0.001585321
5	35	0.030423556	0.010837036	0.000803927
6	35	0.030423556	0.010837036	0.003803639
7	30	0.022352	0.007800855	0.000640172
8	30	0.022352	0.007800855	0.00239819
9	30	0.022352	0.007800855	0.000930023
10	30	0.022352	0.007800855	0.000633621
11	30	0.022352	0.007800855	0.001052797
12	30	0.022352	0.007800855	0.001297851
13	25	0.015522222	0.005322626	0.000480365
14	25	0.015522222	0.005322626	0.002313459
15	25	0.015522222	0.005322626	0.000772352
16	25	0.015522222	0.005322626	0.000885011
17	25	0.015522222	0.005322626	0.000550029
18	25	0.015522222	0.005322626	0.001563232
19	30	0.022352	0.007800855	0.00223702
20	30	0.022352	0.007800855	0.002253137
21	30	0.022352	0.007800855	0.000349474
22	30	0.022352	0.007800855	0.001423662
23	30	0.022352	0.007800855	0.001693455
		Total:	**0.206675024**	**0.038069662**

Appendix H
Table 5: Segment and Node Fuel Consumption for Route 3(Green)

Segment	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Calibrated Fuel Consumption(gal)	Actual Fuel Consumed(gal)
1	45	0.1	0.003623465	0.005626499	0.017205143
2	45	0.549708	0.019918479	0.030929316	0.030142117
3	40	0.449708	0.014601447	0.026356402	0.021279839
4	40	0.460263111	0.014944158	0.026975014	0.012584981
5	30	0.410263111	0.010775982	0.027350207	0.027128023
6	35	0.327648	0.00954958	0.020289476	0.019398045
7	35	0.219576444	0.006399743	0.013597187	0.008750278
8	35	0.419576444	0.012228913	0.02598211	0.020394022
9	35	0.119576444	0.003485157	0.007404725	0.006312075
10	35	0.119576444	0.003485157	0.007404725	0.018905964
11	35	0.019576444	0.000570572	0.001212264	0.001588679
12	35	0.019576444	0.000570572	0.001212264	0.003198544
13	30	0.269576444	0.007080702	0.017971325	0.010143405
14	30	0.127648	0.003352806	0.008509659	0.009875804
15	30	0.077648	0.002039504	0.005176407	0.008451196
16	30	0.027648	0.000726203	0.001843155	0.001491494
17	30	0.077648	0.002039504	0.005176407	0.002426742
18	30	0.027648	0.000726203	0.001843155	0.00080664
19	30	0.027648	0.000726203	0.001843155	0.001679993
20	30	0.027648	0.000726203	0.001843155	0.001260453
21	30	0.077648	0.002039504	0.005176407	0.007917257
22	30	0.127648	0.003352806	0.008509659	0.010831908
23	30	0.177648	0.004666107	0.011842911	0.016854591
24	30	0.427648	0.011232614	0.028509171	0.020969562
25	30	0.477648	0.012545915	0.031842423	0.02805223
26	30	0.127648	0.003352806	0.008509659	0.014430496
27	30	0.177648	0.004666107	0.011842911	0.00532843
			Total:	**0.34477975**	**0.327407907**

Node	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Calibrated Fuel Consumption(gal)	Actual Fuel Consumed(gal)
1	45	0.050292	0.018806252	0.005165607	0.004997799
2	45	0.050292	0.018806252	0.005189363	0.005766522
3	40	0.039736889	0.014484855	0.003996925	0.004267978
4	40	0.039736889	0.014484855	0.004034029	0.005270026
5	30	0.022352	0.007800855	0.002162499	0.002714961
6	35	0.030423556	0.010837036	0.003004168	0.002389455
7	35	0.030423556	0.010837036	0.003004168	0.00050423
8	35	0.030423556	0.010837036	0.003004168	0.002310417
9	35	0.030423556	0.010837036	0.003004168	0.000520915

10	35	0.030423556	0.010837036	0.003004168	0.002240078
11	35	0.030423556	0.010837036	0.003004168	0.003862116
12	35	0.030423556	0.010837036	0.003018113	0.006018375
13	30	0.022352	0.007800855	0.002172537	0.000419789
14	30	0.022352	0.007800855	0.002172537	0.000698529
15	30	0.022352	0.007800855	0.002172537	0.000465492
16	30	0.022352	0.007800855	0.002172537	0.001033429
17	30	0.022352	0.007800855	0.002172537	0.000370732
18	30	0.022352	0.007800855	0.002172537	0.008042972
19	30	0.022352	0.007800855	0.002172537	0.00552107
20	30	0.022352	0.007800855	0.002172537	0.002763657
21	30	0.022352	0.007800855	0.002172537	0.001722263
22	30	0.022352	0.007800855	0.002172537	0.00092517
23	30	0.022352	0.007800855	0.002172537	0.002692629
24	30	0.022352	0.007800855	0.002172537	0.000326675
25	30	0.022352	0.007800855	0.002172537	0.003113719
26	30	0.022352	0.007800855	0.002172537	0.002352198
			Total:	**0.072007057**	**0.071311195**

Table 6: Segment and Node Fuel Consumption for Route 4(Grey)

Segment	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Calibrated Fuel Consumption(gal)	Actual Fuel Consumed(gal)
1	45	0.1	0.003623465	0.005626499	---
2	70	3.749708	0.231394624	0.193797843	---
3	40	0	0	0	---
4	40	0.110263111	0.003580103	0.00646228	---
5	40	0.260263111	0.008450412	0.015253452	---
6	35	0.660263111	0.019243931	0.040886539	---
7	35	0.069576444	0.002027865	0.004308495	---
8	35	0.169576444	0.00494245	0.010500956	---
9	35	0.269576444	0.007857035	0.016693418	---
10	35	0.419576444	0.012228913	0.02598211	---
11	35	0.319576444	0.009314328	0.019789648	---
12	35	0.669576444	0.019515376	0.041463264	---
13	35	0.369576444	0.01077162	0.022885879	---
14	35	0.769576444	0.022429961	0.047655725	---
15	35	0.169576444	0.00494245	0.010500956	---
16	35	0.269576444	0.007857035	0.016693418	---
17	35	0.169576444	0.00494245	0.010500956	---
18	35	0.069576444	0.002027865	0.004308495	---

Node	Speed Limit(mph)	Distance(mi)	Initial Prediction(gal)	Calibrated Fuel Consumption(gal)	Actual Fuel Consumed(gal)
1	45	0.027961704	0.018806252	0.005050014	---
2	70	0.043495983	0.021883904	0.006038605	---
3	40	0.024854848	0.014484855	0.003996925	---

4	40	0.024854848	0.014484855	0.003996925	---
5	40	0.024854848	0.014484855	0.004015391	---
6	35	0.021747992	0.010837036	0.003004168	---
7	35	0.021747992	0.010837036	0.003004168	---
8	35	0.021747992	0.010837036	0.003004168	---
9	35	0.021747992	0.010837036	0.003004168	---
10	35	0.021747992	0.010837036	0.003004168	---
11	35	0.021747992	0.010837036	0.003004168	---
12	35	0.021747992	0.010837036	0.003004168	---
13	35	0.021747992	0.010837036	0.003004168	---
14	35	0.021747992	0.010837036	0.003004168	---
15	35	0.021747992	0.010837036	0.003004168	---
16	35	0.021747992	0.010837036	0.003004168	---
17	35	0.021747992	0.010837036	0.003004168	---
		Total for Nodes and Segments:		**0.552457809**	**0.51**

Note: This route was used to compare overall fuel consumption

Appendix I
Table 7: Bill of Materials

Item	Price
Gas for Driving Routes	$230
AutoTap hardware and software	$0 but if purchased $250
Total Cost:	$230